THE BIOLOGY AND ECOLOGY OF THE BRONZE ORANGE BUG, *MUSGRAVEIA SULCIVENTRIS,* (STÅL) - A LITERATURE REVIEW

PART I - DESCRIPTION, BIOLOGY, HOST SPECIES AND DISTRIBUTION

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Summary

The bronze orange bug, *Musgraveia sulciventris* (Stål) was classified more than 130 years ago and has been recognised as a pest of citrus for more than 100 years. During that time various articles of both scientific and anecdotal nature have been published. Whilst a number of aspects of the bugs biology and ecology have attracted detailed investigation, a number of fundamental areas have received scant attention. This paper collates all the relevant publications on the species and summarises their findings with respect to the insect's classification, description, life cycle, host species and distribution and in doing so highlights those aspects of the bugs biology and ecology that require further investigation.

Introduction

This native insect of the family *Tessaratomidae* has been observed to attack both introduced and indigenous citrus species. Both the late nymphal instars and the adults feed voraciously on the flush growth of host trees from late spring through summer resulting in shoot damage and fruit loss (Hely *et al* 1982). The intensity of infestation is often variable. Severe infestations are infrequently recorded in commercial orchards whereas isolated trees in home gardens from the same district are often more heavily attacked. This variability in attack has resulted in the insect being regarded as a minor pest and, as a result, control measures are only occasionally required.

Irrespective of the insect's pest status, its biology and ecology pose a vast array of questions requiring investigation. There has been a dearth of investigative research into this species - the majority of publications have dealt with anecdotal and observational aspects of its biology and only a limited number of articles of a scientific nature have been published. A thorough search of all literature pertaining to this species has been carried out and the following review aims to present a concise summary of all the published literature, highlighting the salient points raised by each author. This review deals with each article in chronological order under the appropriate sub-heading and only those articles with direct reference to the species are discussed. This review forms the basis of research into many aspects of the bugs biology and ecology. By undertaking this review, those aspects of the bug's biology which are deficient are identified and the work carried out by the various authors used as a reference point from which our research will begin.

Classification

The bronze orange bug, *M. sulciventris,* was first described by Carlo Stål in 1863 (Girault 1924). The original description by Stål, was published in the Transcripts of the Entomological Society of London and was derived from specimens collected at Moreton Bay, Queensland in the same year. The specimens were subsequently included in the collection of the British Museum. The description by Stål was brief and includes descriptions of both male and female specimens. Only the imago was described. Stål classified the species *Oncoscelis sulciventris,* Stål. The

genus *Oncoscelis* was created by Westwood in 1836 and included a second species - *Oncoscelis australasiae*. The species name *sulciventris* is derived from the Latin *sulci* - meaning groove or furrow and *ventris* - meaning below or under. This refers to the groove found on the fourth, fifth and sixth abdominal segments followed by a deep hollow on the anal segment. This groove or furrow is found only in the male of the species.

The species continued to be known as *Oncoscelis sulciventris* until 1895 when Bergroth revised the genus, resulting in its reclassification and inclusion in the genus *Rhoecocoris*. However *Oncoscelis* continued to be used by many authors until at least 1930. In 1957 a further taxonomic revision of the genera in the Australian *Oncomerinae* was undertaken by Leston and Scudder. The justification for the revision included the discovery of the type material for one species of *Oncoscelis*, the realisation that other genera (*Garceus*, Distant and *Peltocopta*, Bergoth) had been placed in the wrong groups and the receipt of specimens referable to the genus *Cumare*, Blote (Leston and Scudder 1957). As a consequence, *M. sulciventris* was again reclassified and a new genus formed in order to accommodate the changes wrought by the revision. The genus *Musgraveia* was thus created, containing two species, namely *sulciventris* and *antennatus* of which *sulciventris* is the type species. The genus *Musgraveia* was named in honour of the distinguished Australian Hemipterist, Anthony Musgrave who was Curator of Entomology at the Australian Museum for many years.

As a result of the revision, Leston and Scudder (1957) produced a key to differentiate the genera of the Australian *Oncomerinae* which then contained 11 genera. In addition, a second key was produced to differentiate the species *M. sulciventris* and *M. antennatus*. To date no additional changes in this classification have occurred and thus the species is known as *Musgraveia sulciventris* (Stål), or by its common name - the bronze orange bug.

Description

Stål's description of 1863 forms the type reference and description of the species. However, many authors have written additional descriptions to that of Stål and from the literature it would appear that there was initial confusion between a number of similar species, viz *Erga* sp., *Stilida* sp. and *Musgraveia* sp. (or *Oncoscelis* as it was known at that time).

Tryon (1889), in what is assumed to be the first Australian publication on *M. sulciventris* named the insect 'the Black Orange Tree Bug (*Erga* sp.)' and derives part of his description from that of Walker (1892) in the Cat. of Hemiptera, Heteroptera. Tryon indicates that there are a number of differences between the specimens he described and Walker's description of *Erga* sp. The confusion is understandable as both species are known to infest citrus and their appearance is superficially similar. There are two observations made by Tryon which are not consistent with the current knowledge of *M. sulciventris*. Tryon states that the 'eggs are laid singly here and there upon the leaves of the orange tree' whereas *M. sulciventris* oviposits in compact rafts; and he further refers to the proboscis as being 'very short' when in fact the proboscis in *M. sulciventris* cannot be considered as short. The balance of the description is consistent with that for *M. sulciventris* and a brief description of late instar nymphs is included, referring to shape, colour and presence of wing buds ie., 'When young this insect is almost regularly elliptical in shape, nearly quite flat above and of a yellow or yellow-red colour' and 'wings and wing-covers are in quite a rudimentary state' (Tryon 1889). As a result of the possible misnaming and minor irregularities in description, it can only be assumed that the species described was *M. sulciventris* and not *Erga* sp.

In 1892, Olliff noted Tryon's confusion between *M. sulciventris* and *Erga* and as a result had specimens compared with Stål's specimens in the British Museum and came to the

conclusion that 'the species of *Oncoscelis,* (now *Musgraveia)* is referred to at some length under the name *Erga* sp. by Tryon'. Olliff also alludes to another species, *Aspongopus,* which is referred to in Koebele's "Report of a Trip to Australia, 1890", (which he suspects is also *M. sulciventris*). Koebele's observations are very brief and he describes only the damage and feeding sites of the 'large hemipterous insect so destructive to the orange in Queensland and New South Wales', but as he provides no description it is not possible to verify his observations as pertaining to *M. sulciventris,* although this is likely to be the case. From Olliff's description and illustrations it is clear that he had correctly identified the species. The description includes eggs, nymphs and adults but with limited detail provided on each life stage other than adults. The description provided for the adult is more detailed than that of Tryon. Illustrations of the adult form and 'rostrum or sucking organ' (Olliff 1892) assist in providing clear and useful aids for identification.

The confusion was further heightened when Froggatt (1901) described 'The Bronzy Orange Bug' as *'Stilida indecora'* but gives the reference as Stål's 1863 description of *Oncoscelis sulciventris.* Reference was made to Olliff's and Tryon's descriptions and in reference to the latter he stated that it 'appears to be the same bug that Tryon describes' and that 'our species damaging the trees on the northern rivers agrees with his description of the Black Orange Bug' (Froggatt 1901). Froggatt's notes indicate that he had observed third, fourth and fifth instar nymphs in October, which was consistent with the life stage that would be expected to be found at that time of year. His description of the nymphal stages was brief. Six years later a correction appeared in Froggatt's 1907 tome, "Australian Insects" in which he states 'I was at first confused with *Stilida indecora* ' (Froggatt 1907) and then he noted the difference between the species. No new description was provided in this reference.

Despite Froggatt's correction in 1907, Froggatt and Gurney (1920) published a brief description of the species under the name 'Bronzy Orange Bug (*Stilida indecora*).' Similarly to Tryon's apparent misnaming of the species, it can only be assumed that the species described was *M. sulciventris*. From the description it is highly likely that they were referring to this species.

There are a number of other minor references to the species during this period (late nineteenth and early twentieth centuries), Lethierry and Severin (1893), Van Duzee (1905) and Kirkaldy (1909). However, these are catalogue and collection notes, and do not contribute greatly to the information on the species other than a note by Van Duzee regarding the similarity between *Stilida* and *Oncoscelis*.

In 1923 Tryon published extensive notes on the species which included the first detailed description of first and second instars. Whilst brief and not in taxonomic style, they are accurate. Tryon was able to demonstrate the concealed presence of second instar nymphs on the citrus trees, which until this time, had not been observed. It was previously assumed that during the winter months the insects 'temporarily disappeared' (Tryon 1923). As a result of Tryon's observations during 1923 the Entomologist-in-Chief directed A.A. Girault to make 'an earnest investigation of the life of the insect and of means for controlling it' (Girault 1924). Girault prefaced the results of his investigations with descriptions of all the life stages. Egg and nymphal stage descriptions were accurate but brief. His descriptions were reinforced by the production of a key to the five nymphal stages. Descriptions of the adult were detailed with differentiation of sexes clearly described. Colour changes both between and within instars were noted.

A further description by Veitch and Simmonds was published in 1929 and draws heavily from that of earlier authors, principally Girault. Whilst brief, the descriptions are supported by photographs of preserved specimens of all life stages. No additional details can be gleaned from this publication. Further publications from 1926 to 1982 from the following authors,Tillyard

(1926), Summerville (1935), Hely (1938, 1944 and 1968), Boschma (1945), Evans (1952), Lester and Scudder (1957) and Hely, *et al* (1982), have summarised the description of the taxonomic features of the insect with little addition to that of early authors. The only exception being Lester and Scudder who made a detailed taxonomic description of the genus *Musgraveia* and a simple key for differentiation of the species when revising the genera of the Australian *Oncomerinae*.

Kumar (1962), presented a paper investigating morpho-taxonomic studies on the genitalia and salivary glands of a range of Pentatomoidea. *M. sulciventris* was used to represent the family Tessaratomidae. The paper provides description of the female external genitalia, supported by illustrations of valvifers, valvula and associated structures. In consideration of the status of *Tessaratomidae*, Kumar considers the group to be highly specialised and that the tribe Oncomerini may merit higher status. Todate no changes to the classification have arisen as result of these investigations.

In 1969, Kumar published an extensive paper which aimed to produce morphological evidence to support the sub-family status for the *Oncomerinae* in the *Tessaratomidae.* He was able to demonstrate 'that the *Oncomerinae* is a homogeneous group and that further subdivision into sub-groups is unwarranted' Kumar (1969). Kumar undertook intensive investigation of representative species from 8 genera of the 14 known genera within the *Oncomerinae.* His investigations encompassed many morphological aspects; alimentary organs, genitalia, immature stages and biology. His work provided detailed taxonomic descriptions for eggs and nymphal stages which were reinforced with illustrations and dimensional data. External male genitalia was well described, and female genitalia was covered in Kumar 1962. No descriptive narrative or illustrations are given for the adult of *M. sulciventris*, however, dimensional data for a small number (6) of specimens is given. This major work by Kumar was followed by a paper by McDonald (1969) which, in addition, to providing detail of the biology of *M. sulciventris,* also included a description of the egg, first and second instars and brief descriptions of the third, fourth and fifth instars. McDonald notes that the rudiments of the female external genitalia are evident on the fifth instar nymph. Additionally, data on the dimensions of each instar were provided. It is worthy of note that the data on the dimensions of specimens presented by Kumar were based upon small sample sizes (6-11 observations) whereas McDonald observed and presented data based upon a much larger sample sizes (38-143 observations).

In conclusion, sound descriptions of external features for all life stages from egg to adult have been published. Descriptions of external genitalia have been produced and published for both male and female specimens.

Anatomy

One author has published on the anatomy of *M. sulciventris.* In a paper discussing the morphology and relationships of the *Pentatomoidea,* Kumar (1969) detailed many of the characteristic differences between the genera of the Tribe *Oncomerinae*, using *M. sulciventris* as the representative of the genus *Musgraveia.* The work on the alimentary canal was comparative in nature and whilst providing the differential characteristics of each genus and the appropriate detail where required an overall description was not given. Diagrams of the alimentary canal and the salivary glands were provided. A similar situation applies to the internal reproductive organs for the male of the species. Anatomy of the female reproductive system is not covered.

A second paper by the same author investigates the structure and function of what was previously known as the ejaculatory reservoir of the male. Kumar found this term 'untenable' and proposed to rename it the 'conducting chamber'. This paper was similar to the previous publication in that it is a comparative study and as such provides descriptive detail and figures on

numerous species from three families within the *Pentatomoidae*, namely *Pentatomidae*, *Scutelleridae* and *Tessaratomidae*. Whilst brief, the comments on the arrangement of the conducting chamber (or ejaculatory reservoir) are significant in the reproductive biology of *M. sulciventris*. It had been observed by a number of authors (eg. Tryon 1923 and McDonald 1969) that a prolonged period is spent in copulation, often as long as 5 days. These observations concur with those of Kumar. Kumar's final comment on the arrangement of the male reproductive system and seminal ducting are very relevant. 'The entire system of canals, it seems, is designed for nothing but the slow transmission of the seminal fluid'.

Overall, Kumar described the structure of some of the anatomical features found in *M. sulciventris,* whilst other aspects have received scant attention and warrant further investigation.

Life Cycle

The life cycle of *M. sulciventris* is akin to all other Heteropteran species in that it undergoes incomplete or hemimetabolous metamorphosis. There are seven discreet life stages which include egg, nymphal instars and the imago. It is a univoltine species with the second instar diapausing during the winter months. It was this characteristic of the life cycle which puzzled orchardists and entomologists for a number of years after the species had become recognised as an economically significant pest. Tryon (1923) in his description of the life cycle reported that orchardists had observed active adult bugs during the summer months and 'then it is said they quite disappear and are not met with, not a single bug during the ensuing winter'. Tryon was able to demonstrate that second instar nymphs could be found by rigorous searching of the tree, primarily the underside of those leaves which are well concealed within the canopy. This work in 1923 and that by Girault in the following year were the first to demonstrate the univoltine nature of the species and to correctly identify all life stages. It is of interest to note an earlier author, (Froggatt 1901) correctly identified different life stages at the appropriate time of the year eg. Froggatt found immature nymphs (third and fourth instars) in October as would be expected at that time of year.

The work of Girault (1924) documented the progression of each instar with time and he was able to observe the progression of the life cycle from the end of diapause (late August) when second instar nymphs commenced feeding. By taking samples weekly he was able to follow the transition through the final four nymphal stages and emergence of adults by late November, thus demonstrating the univoltine nature of the bugs - 'This bug, therefore, develops at an unusually slow rate and it would appear that there is but a single generation during each year' (Girault 1924).

After the work of Tryon (1923) and Girault (1924) subsequent authors have described the life cycle and occurrence of each stadia. (Summerville 1935, Hely 1938,1964, McDonald 1969). Oviposition occurs throughout summer and may extend through to April, with the majority of egg laying taking place in February (Hely 1964). The eggs are deposited in rafts of up to fourteen eggs on the undersides of the leaves. The incubation period is usually about eight to ten days and upon hatching the emergent nymphs remain aggregated around the empty egg raft. No feeding has been observed by this life stage and after four to eight days they moult to the second instar. At this stage there is a major morphological change in the insect, the first instars being globular, light green turgid insects, whereas the second instars are pale green, extremely flattened and semi-transparent. This instar is commonly known as the 'tissue paper' stage and at this point they disperse throughout the canopy of the host tree, secreting themselves on the underside of the foliage in protected locations, ie. where leaves are overlapping. They may aggregate in these sites into large groups - 'often in such numbers as to completely cover the whole underside' (Hely

1964). They locate themselves firmly in place and are very difficult to dislodge (Summerville 1935). It is in this sheltered position that the insect passes the winter 'in a quiescent state' (Summerville 1935). Hely (1964) states 'that this stage undergoes a true diapause, and irrespective of when the eggs are deposited, or to what temperature conditions they are exposed, it is not until growth commences in the spring that they become active' (Hely 1964). The termination of diapause coincides with the appearance of flush growth on the host trees. When diapause terminates the second instar nymphs leave their sheltered positions and move to the ends of the branches where the flush growth is found. It is at this stage, six to eight months after hatching that the insects commence feeding for the first time. After three to four weeks of feeding the nymphs become swollen and bloated and return to the undersides of the leaves where they moult to the third instar. Ecdysis between all instars is carried out suspended on the undersides of leaves or adjacent small branches. Upon completion of moulting the bugs return to feeding sites at the terminal ends of the branches.

The third instars are morphologically similar to the second instars but larger (8-11 mm) (Girault 1924) and are usually margined with black (Hely 1964). The appearance of a 'median spot on the thorax is more often present' (Girault 1924). This 'median spot' is retained in all subsequent instars. Third, fourth and fifth instar nymphs spend a great deal of their time feeding on the flush growth and developing flower petioles. After three to four weeks of feeding, moulting to the fourth instar occurs. Wing buds are visible at this stage and after a further period of feeding of about three weeks, moulting again occurs and the fifth instars appear. Changes in coloration occur during the fourth instar, the nymphs becoming yellow/orange in colour whilst the fifth instars are bright orange initially and as feeding and development progress the orange coloration changes, usually to a 'pinkish or green/grey colour and in their later life they become bloated looking with a waxy or greasy appearance' (Hely 1964). 'The fifth instar is reached about November' (Hely 1964).

Moulting to the imago generally commences in late November (Hely 1964) and by late December the majority of bugs are in the imaginal form. This observation relates to bugs at the southern end of their distribution. Girault (1924) observed appearance of adults at least one month earlier (late October or early November) in the Lismore area. This difference was confirmed by the author's observations in 1993 at Sydney and Lismore. Copulation usually commences eight to ten days after the final moult, with oviposition commencing after a further six to ten days. The reproductive life of the species extends from mid-summer to mid April, with the greatest number of eggs being laid in February (Hely 1964). Eggs subsequently hatch and recommence the cycle.

In summary *M. sulciventris* is a univoltine species with a marked second instar diapause occurring during the cooler months when no food source is available. The vast majority of activity occurs between August and March during which the insects complete their nymphal stages, moult to the imago, become sexually mature and deposit the eggs of the next generation.

Host Species

M. sulciventris has been found to feed and breed on both indigenous and introduced species of citrus. As it is an native species indigenous hosts are of particular importance as they may provide many clues to understanding the behaviour of the bug in cultivated citrus.

Indigenous Hosts.

The first reference to indigenous hosts is found in Tryon's paper of 1923 in which he states that 'The Orange-tree Bug is a native insect and has originally proceeded from some native tree'

(Tryon 1923). Tryon makes a significant point that the native hosts 'comprise not only our species of Wild Lime or Wild Orange (*Citrus australis* Planch. and *Citrus australasica* F. Muell. [now *Microcitrus australis* (Planch.) Swing. and *M. australasica*(F. Muell.) Swing.]) but the other species of Rutaceae' (Tryon 1923). His reasoning behind this conclusion is based upon his observation 'that each year this injurious insect forsakes the orangeries in its haste to repair to the scrubs that contain these trees, to return once more to the orangeries with the advent of spring and reinfest them.' (Tryon, 1923). In light of his subsequent observations and discovery of the concealed diapausing second instars we can perhaps discount his theory of migration. It is Tryon's consideration of host plants of the family Rutaceae rather than specifically the genus *Citrus* which are significant.

Tryon conducted a survey of 'a small native scrub, containing both native citrus and other indigenous Rutaceae plants' in search of *M. sulciventris* but 'failed to find a single Orange-tree bug'. He quotes a W.B. Petrie of the Forestry Department who states that he had never seen the bug on a native citrus, although an insect resembling it was found on '*Pentaceras australis* Hook-fil (Rutaceae)' Tryon 1923. Tryon suspected that this insect may be *Stilidia indecora,* but unfortunately no confirmation is given.

In the following year (1924) Girault refers to Tryon's observation that the insect 'is a native of the scrub, living upon native Citraceae (syn. Rutaceae) allied to the Orange', but, 'no evidence as to this has yet been obtained by the writer' (Girault 1924).

The importance of accurately ascertaining the identity of the native hosts is clearly recognised by early authors and this is also noted by Veitch and Simmonds (1929) but there is no evidence to suggest that any intensive investigations were undertaken.

Summerville (1935) states that 'the bug feeds and breeds on *Citrus australis.'* however, 'the numbers to be found on the indigenous host are very small' (indicating that direct observation of *M. sulciventris* utilising its native host had been observed.) This appears to be the first recorded observation of direct indigenous host/insect interaction. Summerville also comments on the 'carrying capacity' of native hosts indicating that 'a few score individuals on this tree (*Citrus australis*) constitutes a large population' whereas 2000-5000 individuals can be found on cultivated trees (Summerville 1935) Additionally, with reference to migration from native host to orchard trees, Summerville confirms that it occurs but at levels that would not significantly influence orchard populations. His observations also include the location of eggs, first and second instar nymphs and adults on non-citrus plants but states that there is no evidence to suggest that they act as alternate food sources. Other authors have also observed various stages of the insect including eggs, first and second instars and adults on plant species other than citrus. Hely (1964) found eggs on weeds such as *Bidens pilosa* and crops such as peaches. He also notes that nymphs (first and second instars) 'are quite capable of overwintering successfully in these situations, but are incapable of feeding on these plants in the spring' (Hely 1964). The active feeding stages (late second instars, third, fourth and fifth instars) are not recorded on non-citrus hosts thereby providing evidence of host specificity. This view of host specificity is further supported by Hely, *et al* (1982) who state 'The Australian round lime (*Microcitrus australis*) has been seen as a host at Murwillumbah', and confirm that no hosts other than citrus are known.

The only variation to these observations occurs in a 1969 publication by McDonald who states that 'The native plants recorded as hosts are *Atalantia glauca* J. Hook and *Microcitrus australis*'. The species *Atalantia glauca* is synonymous with *Eremocitrus glauca* which is a xerophytic species found in the dry inland areas west of the Great Dividing Range and thus it is unlikely to be a host of *M. sulciventris* which is found only in the humid coastal areas. The two predominant native host species, *Microcitrus australis* and *M. australasica* are both found only in

the rainforests of northern New South Wales and southern Queensland. They are not found west of the Great Dividing Range. *M. australis* is generally found growing in drier conditions than is *M. australasica* and occurs as a tall slender upright tree (9-18m) on the edges of rainforest in the vicinity of Brisbane. The foliage is dimorphic; juvenile foliage being narrow and linear whilst mature leaves are 2.5-5 cm. long and wider in the middle. The fruit is round, rough skinned and 2.5-8 cm. in diameter (Alexander 1983). This species is currently classified as rare and endangered due to encroachment upon its limited habitat. *M. australasica,* or Australian Finger-lime, (which forms the type material for the genus) is by comparison more common and widespread in its distribution, being found as far south as the Richmond River in northern New South Wales. This species occurs as a tall narrow tree up to 10m. Young seedlings are extremely spiny and have small juvenile leaves held on horizontal branches with very short internodes. Upright shoots appear as the plant matures carrying larger leaves with longer internodes and reduced spines. The fruit are long and narrow (6.5-10 cm long and 2.5 cm wide) with thin skins and very acid juice (Alexander 1983).

In conclusion very little is known or confirmed with regard to the interaction of *M. sulciventris* with its indigenous hosts, an area which warrants further investigation as many of the behavioural characteristics currently observed in the species are likely to be a result of coevolution with its native host in its indigenous habitat.

Introduced Hosts

M. sulciventris, like many other insects pests of cultivated crops, has been able to change its host preference from its indigenous host species to that of a related cultivated crop. The first published record of *M. sulciventris* (other than the original description) were from specimens collected on cultivated citrus species where it was found damaging orange trees in the Moreton district of Southern Queensland (Tryon 1889) rather than from its indigenous hosts. Olliff (1892) reports that *M. sulciventris* was found on both oranges and lemons. Froggatt (1901) found 'great numbers of immature bugs upon the wild orange and lemon trees in deserted gardens' in the Lismore District. This was followed by Kirkaldy's notes of 1907 in which he cited *'Citrus aurantium* and *limona'* as the 'food plants'(Kirkaldy 1907).

It was not until 1923 that Tryon documented the range of citrus varieties observed to act as hosts. He stated that *M. sulciventris* will attack 'all kinds of citrus in cultivation - including not only oranges and mandarins, but also lemons and citrons' (Tryon 1923). This observation is echoed by many authors including Tillyard (1926), Veitch and Simmonds (1929), Summerville (1935) and Hely (1938,1944 and 1964).

It was proposed by Summerville (1935) and Hely (1944) that *M. sulciventris* demonstrates some degree of varietal preference. Summerville stated that oranges are preferred to lemons or mandarins but notes that the 'presence of young soft growth is all that is necessary to make any variety acceptable to the pest' (Summerville 1935). The comments of Hely support the view that oranges are the preferred host but he adds 'those trees with thick vigorous foliage are preferred to those trees in poor condition and lacking in vigour which usually escape attack'. This observation is significant for two reasons. Clearly, provision of food sources for subsequent generations is an important factor in oviposition siting and secondly diapausing second instar nymphs require protected sites in which to secrete themselves during the winter period in order to avoid desiccation.

In summary, direct observation of *M. sulciventris* utilising indigenous hosts is scant and limited. The most commonly cited indigenous host are *Microcitrus australis* (syn. *Citrus australis* or Australian Round Lime), and *Microcitrus australasica,* (syn. *Citrus australasica* or

Australian Finger Lime). Other indigenous Rutaceae have been considered as potential hosts but no evidence has been published to demonstrate this. The preference for introduced citrus species which have comparatively thick, dense canopies has been demonstrated by the bugs' commonly observed incidence on those trees and its apparent absence from indigenous species.

Distribution

M. sulciventris is a phytophagus species which is host specific to a limited number of indigenous species within the family Rutaceae. Thus, prior to the development of the citrus industry its distribution was limited to those areas which supported stands of its host plants which were also within the climatically suitable range for the insect. As discussed in previously the distribution of these hosts is limited to the coastal rainforests of north eastern New South Wales and south eastern Queensland and in the absence of contrary literature it is assumed that the distribution of the bug during pre-citrus industry times parallelled that of its native hosts.

The first specimens collected for identification were found at Moreton Bay, Qld. (Stål 1863). With the subsequent development of the citrus industry and use of citrus in home gardens the availability of alternate food sources and substrate increased dramatically. Hence the distribution of the insect was no longer limited by host availability and it has spread into regions in which it was previously unknown. Thus its distribution is now more indicative of climatic parameters which limit range rather than host availability.

With this in mind it is of interest to follow the changing pattern of distribution of *M. sulciventris* since its recognition as a pest. Tryon (1889) recorded the species in orchards in the Toowoomba and Moreton Districts at the localities of 'Cleveland, Stradbroke Island, Nundah and North Pine' all of which are within the range of indigenous host species. In 1892, Olliff referred to orchards which have 'suffered the ravages of this bug on orange and lemon trees at Duranbah, Tweed River and Lismore in northern New South Wales' Froggatt (1901), also noted that the species was plentiful on 'wild oranges and lemons in deserted gardens in Tweed and Richmond River districts.'

Brief catalogue notes by Van Duzee, 1905 and Kirkaldy, 1909, listed the distribution as 'South Queensland and New South Wales' only with no further detail given.

By 1920, the species was clearly recognised as a pest in the 'Northern Rivers district of New South Wales' (Froggatt and Gurney 1920) where it was found to cause significant fruit loss. By 1924 the insect was recorded at Gympie, north of the range of its indigenous host, and at Lismore in the south (Girault 1924).

The possibility that climatic conditions could pose limitations on the distribution of the insect were first postulated by Summerville (1935) when he stated 'The distribution of the insect is obviously controlled largely by climatic influences'. Summerville notes that within its range 'the bug is a major pest only in places of comparatively low average temperatures' and that 'the climatic barrier appears to be insuperable, and that there is no reason to fear any extension of the area of distribution of the pest'. Summerville's hypothesis was only partially correct: it appears that climate does play a significant role in its distribution (limiting it to coastal areas) but its spread along the coastal areas of New South Wales continued unabated. Within three years of Summerville's statement Hely (1938) reports 'the discovery of bronze orange bugs on citrus trees at Branxton and Tenambit' (near Maitland, New South Wales). In the same report Hely states that the previous southern limit of its distribution was Taree (250 km. north of Maitland) 'where it is a familiar pest on citrus trees'.

Hely continued to follow the distribution of the insect, and in 1944 he reported the discovery of 'small infestations in the citrus orchards at Wyong, and one lone adult male at

Mangrove Mountain.' Hely also notes that the insects had been observed by growers in the district for the previous five years.

In a 1964 publication by Hely, the southern extent of the distribution is stated as 'throughout the coastal strip as far south as Wollongong and extending to the eastern slopes of the Great Dividing Range.' Hely also postulated that it may not have reached the full extent of its southern spread, but commented on the insect's inability to become established in inland citrus areas: 'it does appear, however, that the limitations imposed by high temperatures and low humidity will prevent its permanent establishment in the extensive inland citrus districts....' As evidence for this proposition, Hely noted that the insects become distressed during hot dry conditions and descend the trees, clustering on the trunk and ground when screen temperatures reach 106° F and that continued 'extreme conditions may result in a high mortality of bugs in all stages' (Hely 1964).

In the same paper Hely stated that some small infestations had been found in inland north western regions of the state 'within the summer rainfall zone.' Extensive searches of the literature and public collections from Museums have failed to indicate any specific localities of past or present infestations in this region of the state.

The northern distribution of the insect also appears to be limited. Discussions with entomologists at the Queensland Dept. of Primary Industries have indicated that infestations have been reported in the citrus growing areas around Emerald, Biloela and Mundubberra in central Queensland. Thus the current northern distribution does not extend north of the Tropic of Capricorn (23°S).

There is at present no indication that the insect has spread to infest all areas that are climatically suitable for its survival. Further colonisation of currently uninfested areas should be anticipated especially on the south coast of New South Wales.

Conclusion

Whilst our understanding of this occasional pest of citrus has increased substantially over the past century there remains significant areas that are less than complete. Our understanding of the relationship between the insect and its indigenous host, possible alternate hosts and its adopted hosts is one such area. Likewise, the factors limiting its geographical distribution are unknown with certainty. The questions posed by the literature reviewed vastly outnumber the answers provided by it and in doing so provide the impetus for further research. Part II of this document deals with a review of behavioural aspects which influence its pest status.

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